Journal of Forestry Research (2014) 25(1): 129–134
DOI 10.1007/s11676-014-0437-2

ORIGINAL PAPER

Estimation of the carbon pool in soil and above-ground biomass within mangrove forests in Southeast Mexico using allometric equations

Jesús Jaime Guerra-Santos • Rosa María Cerón-Bretón • Julia Griselda Cerón-Bretón
Diana Lizett Damián-Hernández • Reyna Cristina Sánchez-Junco
Emma del Carmen Guevara Carrió

Received: 2012-08-30; Accepted: 2013-05-28

Abstract: We report the results of carbon stored in soil and aboveground biomass from the most important area of mangroves in Mexico, with dominant vegetation of Red mangrove (*Rhizophora mangle* L.), Black mangrove (*Avicennia germinans* L.), white mangrove (*Laguncularia racemosa* Gaertn.) and button mangrove (*Conocarpus erectus* L.). We sampled soils with high fertility during the dry season in 2009 and 2010 at three sites on Atasta Peninsula, Campeche. We used allometric equations to estimate above ground biomass (AGB) of trees. AGB was higher in *C. erectus* (253.18±32.17 $t \cdot ha^{-1}$), lower in *A. germinans* (161.93±12.63 $t \cdot ha^{-1}$), and intermediate in *R. mangle* (181.70±16.58 $t \cdot ha^{-1}$) and *L. racemosa* (206.07±19.12 $t \cdot ha^{-1}$). Of the three studied sites, the highest absolute value for AGB was 279.72 $t \cdot ha^{-1}$ in button mangrove forest at any single site. Carbon stored in soil at the three sites ranged from 36.80±10.27 to 235.77±66.11 $t \cdot ha^{-1}$. The Tukey test (p <0.05) made for AGB was higher for black mangrove showed significant differences in soil carbon content between black mangrove and button mangrove. *C. erectus* had higher AGB compared with the other species. *A. germinans* trees had lower AGB because they grew in hypersaline environments, which reduced their development. *C. erectus* grew on higher ground where soils were richer in nutrients. AGB tended to be low in areas near the sea and increased with distance from the coast. *A. germinans* usually grew on recently deposited sediments. We assumed that all sites have the same potential to store carbon in soil, and then we found that there were no significant differences in carbon content between the three samples sites: all sites had potential to store carbon for long periods. Carbon storage at the three sampling sites in the state of Campeche, Mexico, was higher than that reported for other locations.

Key words: carbon storage, *Rhizophora mangle*, *Laguncularia racemosa*, *Avicennia germinans*, tree biomass

Introduction

Carbon dioxide (CO_2) is emitted to the atmosphere both naturally and from anthropogenic disturbances. It is the most important greenhouse gas and accounts for 55% of global warming. The concentration of CO_2 in the atmosphere increased from 543 $mg \cdot m^{-3}$ in 1750 to 711 $mg \cdot m^{-3}$ in 1999, with the observed increase due mainly to the oxidation of organic carbon from fossil fuel use and deforestation (IPCC 2001). The main carbon (C) stocks in forest ecosystems are soil, vegetation and humus. Vegetation assimilates carbon and incorporates it into its structure where it is fixed and stored for long periods through photosynthesis. Forests are therefore important carbon sinks (Ordoñez and Masera 2001). The foliage of trees adds organic matter to the soil as leaves decompose and incorporate CO_2 into the soils. This gives rise to stable humus, which in turn, adds additional CO_2 (Ordoñez et al. 2001).

Wetlands are known to be important carbon sinks despite occupying only about 5% of the planet's surface. Wetlands contain much of the world's carbon reservoir (Komiyama et al. 2008). Globally, wetlands store an estimated 300 to 700 billion tons of carbon (Bridgham et al. 2006). Wetland soils store carbon for long periods due to phreatic groundwater, high productivity and slow decomposition due to slow diffusion of oxygen (Whiting and Chanton 2001).

Field studies of biomass and productivity in mangrove forests are difficult due to muddy soil conditions. Three commonly methods used to estimate forest biomass are: 1) the destructive

The online version is available at http://www.springerlink.com

Jesús Jaime Guerra-Santos (✉) • Rosa María Cerón-Bretón • Julia Griselda Cerón-Bretón • Diana Lizett Damián-Hernández • Reyna Cristina Sánchez-Junco • Emma del Carmen Guevara Carrió
Centro de Investigación de Ciencias Ambientales-Universidad Autónoma del Carmen, Av. Abasolo s/n. Col. Renovación 2da. Sección C.P. 24180. Cd. del Carmen, Campeche, México.
Phone +52 938 3811018 extension 1806; Fax +52 938 3811018.
Email: jguerra@pampano.unacar.mx

Corresponding editor: Hu Yanbo

method, 2) the average tree method, and 3) the allometric method. With the destructive method, trees are felled. This is not practical in mature forests where trees can weigh up to several tons. In addition, it is difficult to reproduce the results. The average tree method is usually applied only in forests with a homogeneous distribution of tree size, as in the case of plantations (Komiyama et al. 2008). The allometric method uses allometric equations to estimate the partial or total weight of a tree from measured dimensions such as diameter at breast height (DBH) and tree height (Komiyama et al. 2005).

The state of Campeche ranks first nationally with over 259,000 ha of mangrove coverage. These mangroves are located in the protected area "Laguna de Términos", considered the most important wetland area in the Gulf of Mexico. The main threats to these mangrove forests arise from human activities inland on Atasta Peninsula (INE 1997). These include agriculture, aquaculture, oil production, and population growth. The mangrove forests located in this region are of national ecological and economic importance. We reported the carbon stored in soil and tree biomass, the latter estimated by allometric equations, in a mangrove forest located in the Atasta Peninsula in Campeche, Mexico. We used the allometric equation method because it does not require felling of trees and is therefore useful to estimate temporal changes in forest biomass through subsequent measurements.

Materials and methods

Site description

Our study area was in south-western Campeche state and part of the municipality of Carmen. The geomorphology of the area consists of wetlands and floodplains at elevations between 0 and 20 m. The soils of the region are characterized by heavy clay with high fertility and the predominant vegetation is mangrove forest, including *Rhizophora mangle*, *Avicennia germinans*, *Laguncularia racemosa*, and *Conocarpus erectu* (INE 1997). The study area has three well-defined seasons: dry (February to May), rainy (June to October) and cold (November to February).

We sampled at three sites in our study area, Puerto Rico, Xicalango, and Nuevo Campechito (Table 1). All three sites had average rainfall of 1,680 mm, four months of dry season, and all were categorized as wet mangroves

Puerto Rico was located at 18°36'55" N and 91°56'35" W, at an elevation of 11 meters. We classified this mangrove as a basin, as described by Lugo and Snedaker (1974). The sampling plots were located inland on sites with minimal slope gradient. The water turnover was very slow, with floodwaters accumulating in depressions. This type of site corresponds to what Twilley et al. (1986) describe as a cycle of organic matter and nutrients in a closed ecosystem. Mangrove species *Avicennia germinans*, *Laguncularia racemosa*, and *Rhizophora mangle* were recorded on this site.

Xicalango was located at 18°37'02" N and 91°58'20" W, at an elevation of 12 m. The mangrove forest at this site was a slow-growing mixed mangrove as described by Rico-Gray (1982) and supporting species *A. germinans*, *L. racemosa* and *C. erectus*. Our sampling plots were located inland near a stream that connected the Pom-Atasta lagoon system. Soils were yellowish brown with abundant aquatic fungi and bacteria, and low salinity. This was a dense mangrove. Tree heights ranged from 3 to 6 m, and trees had adventitious roots that impeded access.

Nuevo Campechito was located at 18°38'28" N and 92°27'29" W, at 1 m a.s.l. elevation. Like Puerto Rico, this mangrove forest was of the basin type (Twilley et al. 1986) and grew on a coastal plain with poor drainage. The selected sampling plots were bordered by two small lakes, with major mangrove species *A. germinans*, *L. racemosa* and *C. erectus*.

Fig. 1. Location of the study area and sampling sites Puerto Rico, Xicalango and Nuevo Campechito

Table 1. List of study sites, mangrove species, geographic coordinates, and maximum DBH of mangrove trees

Sampling site	Species	geographical coordinates	Maximum DBH (cm)
Puerto Rico	*Rhizophora mangle, Laguncularia racemosa, Avicennia germinans*	18º36'55" N, 91º56'35" W	49.8
Xicalango	*Laguncularia racemosa, Avicennia germinans, Conocarpus erectus*	18º37'02" N, 91º58'20" W	2.93
Nuevo Campechito	*Rhizophora mangle, Laguncularia racemosa, Avicennia germinans, Conocarpus erectus*	18º38'28" N, 92º27'29" W	7.8

Importance value

The Importance Value enables ranking of the importance of species within a forest and is based on density, frequency and dominance. It was calculated as division by 3 of the sum of relative density, relative frequency, and relative dominance.

Method of sampling and forest inventory

Soil samples were collected at each of our three-mangrove forest sites. Samples were collected during the dry season in 2009 and 2010. Each site was selected based on its representation of the

region, vegetation type, accessibility, and hydrology. Plots to collect soil samples during 2009 and 2010 at each site were 18 m^2. Six plots were established at Puerto Rico, and three plots were established at both Nuevo Campechito and Xicalango. Three samples were collected from within each plot on a linear transect through the plot at spacing of one meter. We took samples at three different soil depths, this is according with Craft et al. 1991 during the dry seasons of 2009 and 2010. Soils were sampled to 0.30 m depth using a corer of 193.3 cm^3 and included surface organic matter from each site. After extraction, each sample was labelled, sealed, and processed in the laboratory for analysis. The forest inventory was made randomly no stratified, we made previous observation looking for plots that had the same characteristics in tree cover, flooding and composition.

In the laboratory, shells and bits of organic material (roots, leaves and branches) were removed from soil samples. The samples were then air-dried and passed through a 2-mm sieve. For quantification of organic carbon (CO), we used the method of loss on ignition. This consisted of measuring the weight loss of organic matter after heating at 550°C for 4 h (Heiri et al. 2001) and then converting this to CO by a multiplication factor of 0.4 (Craft et al. 1991). Carbon (C) stored was calculated using the following formula:

$$C = CO\% \times Da \times \mathrm{Pr} \tag{1}$$

where C = carbon stored ($ton \cdot ha^{-1}$); CO% = percentage of carbon in the soil, Da = apparent density ($t \cdot m^{-3}$) and Pr = depth (m) (Gonzalez et al. 2008).

For the forest inventory the trees were sampled in 12 rectangular plots of 200 m^2 (10 m × 20 m) distributed in the same way in the three sampling sites of the Carbon samples. DBH was recorded at 1.30 m above the soil surface for all species except *R. mangle*, where DBH was measured at 1.30 m above the adventitious roots. Data were collected from 321 trees, the DBH was measured only on those trees more than 1 cm of DBH

Electrical conductivity (EC) was measured by a conductivity meter CL 35 in an extract suspended in a 1:5 soil:water solution (NOM-021-RECNAT-2001). Average values were obtained for the different laboratory determinations. Our null hypothesis was that all sites had similar levels of carbon storage. Carbon storage was evaluated using one-way ANOVA to assess differences between sample sites and sample plots within sites. The evaluation was conducted by testing the standardization and homogeneity of variances (p <0.05) by Tukey's method, using Statistica version 7 software.

Allometric models were used to estimate above-ground tree biomass (AGB). These models were developed from destructive sampling for mangrove forests around the world (Table 2). The model used in this study (equation 2) was based on samples of 2,410 trees from different tropical forests, including 27 study sites distributed throughout the tropics (Chave et al. 2005).

Table 2. Allometric equations for estimating tree biomass (AGB in kg) of mangroves, p = wood density ($t \cdot m^{-3}$). The densities are *Avicennia germinans* = 900, *Laguncularia racemosa* = 762, *Rhizophora mangle* = 1000, and *Xylocarpus granatum* = 700

Equation	Species	Area	Source
$AGB=0.140DBH^{2.40}$	*Avicennia germinans*	French Guyana	Fromard et al. (1998)
$AGB=0.140DBH^{2.54}$	*Avicennia germinans*	Guadeloupe, French Antilles	Imbert and Rollet (1989)
$AGB=0.102DBH^{2.50}$	*Laguncularia racemosa*	French Guyana	Fromard et al. (1998)
$AGB=0.209DBH^{2.24}$	*Laguncularia racemosa*	Guadeloupe, French Antilles	Imbert and Rollet (1989)
$AGB=0.178DBH^{2.47}$	*Rhizophora mangle*	Guadalupe, French Antilles	Imbert and Rollet (1989)
$AGB=0.0823DBH^{2.59}$	*Xylocarpus granatum*	West Australia	Clough and Scott (1989)
$AGB=0.251pDBH^{2.46}$	Common	Tropical Forest in America, Asia, and Oceania	Komiyama et al. (2005)
$AGB=p(\exp(-1.349+1.980Ln(DHB)+0.207(Ln(D))^2-0.0281(Ln(DHB))^3)$	Common	Southwest of Asia	Chave et al. (2005)

We followed Cheve et al. (2005) to adjust equation 2 for use in our study because our sampling sites contained mixed rather than single-species forests:

$$AGB = p(\exp(-1.349 + 1.980\ln(DBH) + 0.207(\ln(DBH))^2 - 0.0281(\ln(DBH))^3) \tag{2}$$

where p is the density of the wood and DBH is the diameter of the trunk at breast height. This model assumes a constant ratio between the diameter and height, which was useful because we did not estimate tree height. Wood density was extracted from the database Global Wood Density (Zanne et al. 2009).

The AGB carbon content was evaluated as 50% of the dry weight biomass (Basuki et al. 2009).

Results and discussion

Importance value

At the Puerto Rico site, *A. germinans* had the highest importance value, and *L. racemosa* the lowest. Similar results were reported for *A. germinans* in plots located in other areas of Laguna de Terminos in mangrove forests of the river type (Day et al. 1987). Importance values for Nuevo Campechito contrasted sharply with Puerto Rico, with the maximum value obtained for *L. racemosa* and the minimum for *A. germinans*. Puerto Rico had the lowest density of trees, but the largest diameter and basal area. On the other hand, Xicalango had the minimum values for di-

ameter and basal area. Nuevo Campechito had the highest tree density. At Xicalango, all three mangrove species (*A. germinans*, *L. racemosa* and *C. erectus*) had the same importance value (Table 3).

Table 3. Composition of trees in mangrove forests at sampling sites Puerto Rico, New Campechito and Xicalango

Site	species	Density (stem·ha^{-1})	Frequency	DBH mean (cm)	basal area (m^2 ha^{-1})	Importance value^2
Puerto Rico	*Avicennia germinans*	9050	78.06	11.09	13.31	78.06
	Laguncularia racemosa	1100	9.71	9.74	3.69	9.71
	Rhizophora mangle	1400	12.23	11.33	1.77	12.23
	Total	11550			18.77	100
Nuevo Campechito	*Avicennia germinans*	2780	7.42	6.46	3.47	7.42
	Laguncularia racemosa	12220	33.83	2.49	2.37	33.83
	Rhizophora mangle	7780	25.42	2.2	1.96	25.42
	Conocarpus erectus	10000	33.33	1.28	1.3	33.33
	Total	32780			9.1	100
Xicalango	*Avicennia germinans*	6667	33.33	1.64	1.41	33.33
	Laguncularia racemosa	13889	33.33	1.14	1.42	33.33
	Conocarpus erectus	3333	33.33	1.19	0.37	33.33
	Total	23889			3.2	100

Above-ground biomass (AGB) by species

The highest average AGB was recorded for *C. erectus* (253.18 t·ha^{-1}, p <0.05), and the lowest for *A. germinans* (161.93 t·ha^{-1}, p <0.05). Species with intermediate tree biomass were *R. mangle* 181.70 t·ha^{-1} (p <0.05), and *L. racemosa* 206.07 t·ha^{-1} (p <0.05) (Fig. 2).

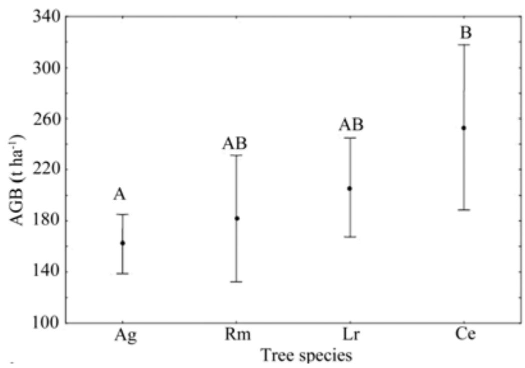

Fig. 2. Mean above-ground biomass (AGB in t·ha^{-1}) of four species (Ag = *A. germinans*, Rm = *R. mangle*, Lr = *L. racemosa* and Ce = *C. erectus*). Means with the same letter are similar at p<0.05.

AGB was significantly greater for *C. erectus* than *A. germinans*. *A germinans* trees had lower AGB documented in previous reports. This might be because the trees grew in hypersaline environments where development can be retarded (Komiyama et al. 2008).

C. erectus grew on elevated lands where soils had higher nutrient content. AGB tended to be low in mangroves near the sea and increased with distance from the coast. *A. germinans* typically grew on recently deposited sediments. The Tukey test showed that there are not significant differences among the sample sites, three sampling sites had similar levels of carbon stored in trees (Fig. 3) and soil (Fig. 4). For tree biomass carbon, however, Xicalango had the maximum value (114.37±12.74 t·ha^{-1}) while the minimum value was recorded at Puerto Rico (77.46±9.17 t·ha^{-1}). In this case, the measured trees had similar diameter sizes. The highest density of *C. erectus* was found at Xicalango, which explains the higher level of carbon stored.

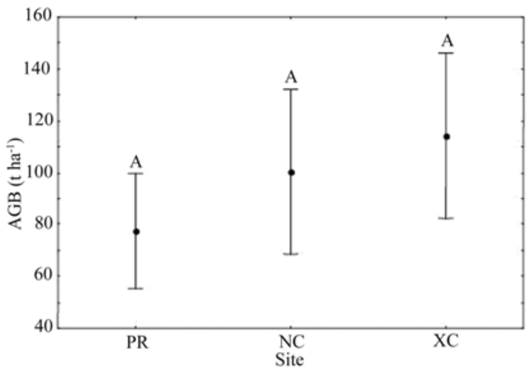

Fig. 3. Mean carbon content in above-ground tree biomass (AGB, t·ha^{-1}) at three sampling sites (PR = Puerto Rico, NC = New Campechito and XC = Xicalango). Means with the same letter are similar at p <0.05.

Carbon storage in soils

The carbon stored in soils of the three sites ranged from 33.61 to 480.26 t·ha^{-1}, greater than that reported by Arreaga (2002) or Webb (2002). The maximum value was recorded for soils at Puerto Rico (480.26 t·ha^{-1}) and the minimum value at Nuevo Campechito (33.61 t·ha^{-1}). The plots at Puerto Rico had the highest density of *A. germinans*. This species grew on land with high organic matter accumulation due to low soil decomposition rates. These soils were continuously flooded, and the resulting high concentration of salts inhibited decomposition. This could

explain the high soil carbon content less dense forest at Puerto Rico.

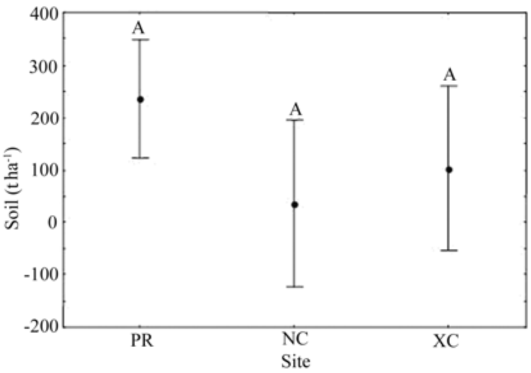

Fig. 4. Mean carbon content in soil (t·ha^{-1}) at three sampling sites (PR = Puerto Rico, NC = New Campechito and XC = Xicalango). Means with the same letter are similar at p <0.05.

The carbon stored in AGB (Table 4) differed significantly between mangrove forest plots (p <0.05), averaging 184.76 t·ha^{-1}. Plots (P) 4, 9 and 10 showed significantly higher AGB compared to other plots with a total AGB absolute value of 279.72 t·ha^{-1}. This is the greatest value in this Mexican forest and it can be compared with the Swamp forest in Tropical Africa with 276.6 t·ha^{-1} (Basini et al. 2008). *C. erectus* and *L. racemosa* are the dominant species in the mangrove site Xicalango (P9 and P10, respectively), while mangrove site Puerto Rico (P4) has an association of the *A germinans* with *R. mangle* trees, which are known for a high abundance of relatively large trees in these specific communities.

Table 4. Mean values of tree biomass (AGB), carbon content in AGB, and soils of mangrove forests at Atasta Peninsula, Campeche, México.

Site	Plot	AGB (t·ha^{-1}, mean±ES)*	AGB-carbon (t·ha^{-1}, mean±ES)	Soil (t·ha^{-1}, mean±ES)
PR	P1	116.45±7.22	58.22±3.61	64.18±10.52
PR	P2	145.46±14.68	72.73±7.34	73.46±7.89
PR	P3	165.29±46.10	82.65±23.05	480.26±30.34
PR	P4	236.90±47.76	118.45±23.88	356.02±77.30
PR	P5	113.80±6.69	56.90±3.34	202.89±49.58
PR	P6	151.67±15.36	75.84±7.68	237.82±10.49
NC	P7	169.56±45.58	84.78 ±22.79	54.85±17.52
NC	P8	162.03±21.29	81.01±10.64	33.61±5.60
NC	P9	269.80±41.79	134.90±20.90	19.53±13.18
XC	P10	279.72±29.00	139.86±14.50	116.88±26.16
XC	P11	203.24±23.75	101.62±11.88	74.10±4.16
XC	P12	203.25±27.60	101.63±13.80	119.50±20.40
Mean		184.76±8.86	92.38±7.92	152.76±41.062

ES= Standard Error.*Allometric equation based on Chave et al. (2005). (PR = Puerto Rico, NC = New Campechito and XC = Xicalango)

Plots 1, 2 and 5 (mangroves in Puerto Rico) had not significant difference in AGB, but showed significant differences when compared with the P4 (mangrove in Puerto Rico), P9 and P10 (mangroves in Xicalango).

The lowest values of AGB were observed in P1, P2 and P5 (mangroves in Puerto Rico), these three plots are dominated by *A. germinans*, and were the most disturbed from the anthropogenic point of view.

Plots P3, P6 (mangroves in Puerto Rico), P7, P8 (mangroves in Nuevo Campechito), P11 and P12 (mangroves in Xicalango) showed no significant difference in AGB amongst them. The AGB results of plot 4 (mangroves in Puerto rico) were higher than those reported by Fromand et al. (1998) in French Guyana.

All these plots discussed above are associated with R mangle and Avicennia (Table 3) for mangroves for the associations. Fromand et al. (1998) has reported that in forests with these associations (143.3 and 122.2 t·ha^{-1}), the carbon content in the biomass follows the same trend as the AGB.

Plots P3, P4, P5 and P6 show the highest values of carbon stored in soil, ranging from 202.89 to 480.26 t·ha^{-1}. However, plots P3 and P4 show significant differences in carbon stored in soil (p <0.05) when compared to the carbon stored in soil in plots P5 and P6.

Defoliation of these species incorporates a high content of organic matter to the soils. In addition, we observed the flooding conditions prevailing at these sites induce the soils to store large amounts of carbon (Komiyama et al. 2008). The remaining plots averaged soil carbon from 19.53±13.18 to 119.50±20.40 t·ha^{-1}. It can be inferred that the topographical and hydrological conditions are the cause of these values.

Differences were found between the content of carbon stored in the studied plots. While mangrove forests are major reservoirs of carbon in their soils, the carbon storage is influenced by topographical and hydrological conditions. For example, soils with higher water logging (P3, P4, P5, and P6) had larger stores of carbon, as compared to the driest sites (P8 and P9). Despite having low values of AGB, the P3 and P4 plots showed higher total carbon content. The lowest total carbon occurred at P1 and P8 (Fig. 5).

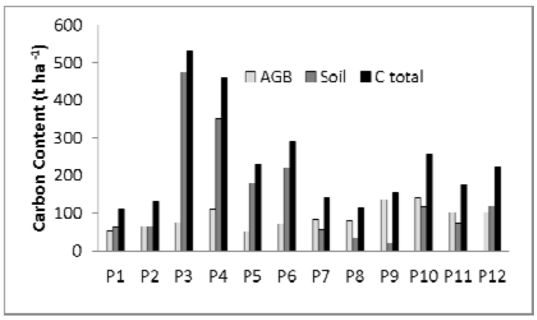

Fig. 5. Carbon content in soil and Above Ground Biomass (AGB), and the total carbon (C Total) in the different plots for the mangrove forest in Campeche, Mexico. The bars indicate the standard error.

All sites showed high values of EC, with 2.93±0.35, 5.18±0.26 and 17.78±0.77 dS·m^{-1} for New Campechito, Xicalango and Puerto Rico, respectively (Fig. 6). The EC values are indicators of salinity. High salinity is therefore indicated for Puerto Rico and moderate salinity for Xicalango and New Campechito. We determined high salinity at Puerto Rico and could be probably attributed to the low permeability observed of the soil, which

contributes to the accumulation of water by increasing the concentrations of Na and contributing to low micro biota activity. It is noteworthy that *A. germinans* is the species that tolerates the highest salinity (Kamiyama et al. 2008), which is why it was most abundant at this site.

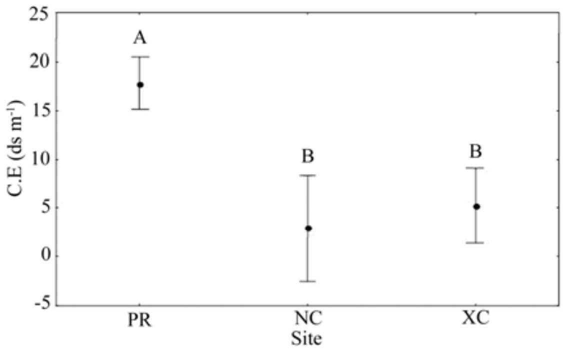

Fig. 6. Mean values of EC (dS· m^{-1}) of the three sites (PR = Puerto Rico, NC = New Campechito and XC = Xicalango). Means with the same letter are not significant.

Conclusions

Based on the results of this study (Table 4) and compared with previous reports (Fromand et al. 1998), all the studied sites have potential to store carbon for long periods. Mangrove forests also have high productivity and are a source of nutrients. The factors, which work synergistically with the hydrology and low decomposition rate, result in high storage rates. The maximum carbon storage content was found in soils at the Puerto Rico site. The results of this study, one of the few assessments of above ground biomass (AGB) and carbon storage in mangrove forests of the humid tropics of Mexico, and in particular in the state of Campeche, show that the soils have potential to be reservoirs of carbon. Sites with larger and denser trees have greater AGB. Some mangrove species tend to grow to larger sizes and some mangals have more dense stands of trees. But the mix of species is only relevant to AGB with reference to the dimensions of trees by species.

The recorded AGB values were influenced by the mangrove species occurring at each site. It was found that plots with predominance of *C. erectus* showed higher values of AGB while those plots with associations predominating *A. germinans* showed lower values of AGB.

References

Amarasinghe MD, Balasubramaniam S. 1992. Net primary productivity of two mangrove forest stands on the northwest coast of Sri Lanka. *Hydrobiology*, **247**: 37–47.

Arreaga W. 2002. Carbon storage in forest with a management program in the natural reserve “Maya Peten”, Guatemala. Thesis M. Sc. CATIE, Turrialba, CR. p.86.

Baccini A, Laporte N, Goetz S J, Sun M, Dong H. 2008. A first map of tropical Africa’s above-ground biomass derived from satellite imagery. *Environmental Research Letters* **3**(4): 1–9.

Basuki TM, Van Laake PE, Skidmore AK, Hussin Y A. 2009. Allometric equations for estimating the above-ground biomass in tropical lowland Dipterocarp forest. *Forest Ecology and Management*, **257**: 1684–1694.

Bridgham SD, Megonigal JP, Keller JK, Bliss NB, Trettin C. 2006. The carbon balance of North American wetlands. *Wetlands,* **26**: 889–916.

Chave J, Andalo C, Brown S, Cairns MA, Chambers JQ, Eamus D, Folster H, Fromard F, Higuchi N, Kira T, Lescure JP, Nelson BW, Ogawa H, Puig H, Rie´ra B, Yamakura T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. *Oecologia*, **145**: 87–99.

Craft CB, Seneca ED, Broome SW. 1991. Ignition and kjeldahl digestion for estimating organic carbon and soils: Calibration with dry combustion. *Estuaries*, **14**: 175–179.

Day JW, Conner WH, Ley LF, Day RH, Navarro AM. 1987. The productivity and composition of mangrove forests, Laguna de Terminos, Mexico. *Aquatic Botany*, **27**: 267–284.

Fromard F, Puig H, Mougin E, Marty G, Betoulle JL, Cadamuro L. 1998. Structure above-ground biomass and dynamics of mangrove ecosystems: new data from French Guiana. *Oecologia*, **115**:39–53.

Gonzalez M, Etchevers B, Hidalgo M. 2008. Carbono en suelos de ladera: factores que deben considerarse para determinar su cambio en el tiempo. *Agrociencia*, **42**(7): 741–751.

Hawes JE, Peres CA, Riley LB, Hess LL. 2012. Landscape-scale variation in structure and biomass of Amazonian seasonally flooded and unflooded forests. *Forest Ecology and Management,* **281**: 163–176.

Heiri O, Lotter AF, Lemcke G. 2001. Loss on ignition as a method for estimating organic and carbonate content in sediments: reproducibility and comparability of results. *Journal of paleolimnology*, **25**:101–110.

Instituto Nacional de Ecología. 1997. Programa de Manejo del área de protección de flora y fauna “Laguna de Términos”; *SEMARNAT*. México. p.167.

IPCC (Intergovernmental Panel on Climate Change). 2001. Climate Change: The Scientific Basis. Cambridge, UK: Cambridge Univ. Press, p.881.

Komiyama A, Ong JE, Poungparn S. 2008. Allometry, biomass, and productivity of mangrove forests: a review. *Aquatic Botany,* **89**: 128–137.

Komiyama A, Poungparn S, Kato S. 2005. Common allometric equations for estimating the tree weight of mangroves. *Journal of Tropical Ecology*, **21**: 471–477.

Lugo A, Snedaker C. 1974. The ecology of mangroves. *Annual Review of Ecology and Systematics*, **5**: 38–64.

Mall LP, Singh VP, Garge A. 1991. Study of biomass, litter fall, litter decomposition and soil respiration in monogeneric mangrove and mixed mangrove forest of Andaman Island. *Tropical Ecology*, **32**: 144–152.

Ordoñez JA, Masera O. 2001. Captura de carbono ante el cambio climático. *Madera y Bosques*, **7**: 3–12.

Ordoñez JA, Bernardus HJ, Masera O. 2001. Almacenamiento de carbono en un bosque de *Pinus pseudostrobus* en Nuevo San Juan Michoacan *Madera y Bosques,* **7**(2): 27–47

Rico-Gray V. 1982. Estudio de la vegetación de la zona costera inundable del noroeste de Campeche, México: Los petenes. *Biótica*, **7**: 171–188.

Twilley RW, Lugo AE, Patterson-Zucca C. 1986. Litter production and turnover in basin mangrove forests in Southwest Florida. *Ecology*, **67**: 670–683.

Webb A. 2002. Pre-clearing soil carbon levels in Australia. *National carbon accounting system technical report No.12*. Australian greenhouse office, Canberra, 204.

Whiting JG, Chanton JP. 2001. Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration. *Tellus,* **53**B: 521–528.

Zanne AE, Lopez GG, Coomes DA, Llic J, Jansen SL, Lewis SL, Miller RB, Swenson NG, Wiemann MC, Chave J. 2009. *Global wood density database*. Dryad. Identifier: http://hdl.handle.net/10255/dryad.235. August 4th 2012